Final Report Joint Fire Science Program
Project: Quantification of Canopy Fuels in Conifer Forests
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This final report details objectives, accomplishments, findings and proposed and accomplished deliverables.

Objectives: The project had three general objectives:

- develop and test alternative indirect methods of quantifying canopy fuels against direct measurement,
- produce a canopy fuels photo guide to help wildland managers "develop an eye" for canopy fuels, and
- create a simulation program so that fire managers and silviculturists can estimate the impacts of potential treatments on canopy fuels.

Accomplishments: We destructively sampled canopy fuels in a small number of forest types, using repeated entries to progressively remove trees and "treat" stands to sequentially sparser residual densities. At each level of treatment indirect measures of canopy fuels were be derived and sampled, and photographs taken. Treatments were removal from below of 25%, 50% and 75% of stand basal area. The primary objective of this study was to correlate these indirect measures with the known, destructively sampled values.
Two basic indirect approaches were explored. The first approach used the LAI 2000 plant canopy analyzer and the second used tree inventory data in combination with existing allometric equations of plant biomass.
Finally, this project developed software computer for silviculturists and fire managers. Our methods were incorporated into the Fire and Fuels Extension to the Forest Vegetation Simulator (Reinhardt and Crookston 2003), and also into the FuelCalc software. FuelCalc is in turn incorporated into the FIREMON monitoring and analysis system. It is also being further developed with support from JFSP 05-4-3-10.

Sampling was conducted in the summer of 2000 and 2001. Five study sites were selected.

Table 1. Locations and characteristics of study sites.

Study site	Forest type	Location	Elevation (m)	Basal Area (m2/ha)	QMD (cm)	Density of trees > 10 cm (trees/ha)	Stand height (m)
Blodgett	Sierra Nevada mixed conifer	Blodgett Forest Research Station, CA	1300	46.8	35.1	325	34
Flagstaff	PP	Coconino National	2308	69	18.8	2067	15

		Forest, AZ					
Ninemile	PP/DF	Lolo National Forest, MT	1050	30.5	17.9	481	22
Salmon	DF/LP	Salmon-Challs National Forest, ID	2300	37.7	15.2	1209	17
Tenderfoot	LP	Lewis and Clark National Forest, MT	2290	42.7	15.5	1145	19

Major findings:

1. Canopy fuel characteristics were documented in detail for 5 study sites at 4 treatment levels in the western U.S. This work presents the only (that we are aware of) work of its kind, where canopy fuel biomass was destructively sampled on an entire plot and quantified by vertical and horizontal distribution.

Table 2. Canopy and stand characteristics by study site and treatment level. CBD is canopy bulk density, kg/m^3, CBH is canopy base height, m, and CFL is available canopy fuel load, kg/m^2.

Site	Treatment	Basal Area (m^2/ha)	CBD (kg/m^3)	CBH (m)	CFL (kg/m^2)	Canopy Cover (%)
Ninemile	Untreated	30.42	.089	0	1.40	Missing
	Understory removed	29.71	.086	1	1.33	59
	75% original basal area	23.31	.055	5	0.76	50
	50% original basal area	16.60	.037	11	0.40	30
	25% original basal area	9.23	.022	12	0.24	19
Salmon	Untreated	36.26	.257	1	2.09	70
	75% original basal area	27.24	.222	2	1.69	59
	50% original basal area	18.84	.153	3	1.19	47
	25% original basal area	8.16	.069	5	0.55	24
Flagstaff	Untreated	69.02	.166	5	0.93	69
	75% original basal area	53.21	.147	6	0.80	52
	50% original basal area	35.89	.104	7	0.54	42
	25% original basal area	17.79	.057	9	0.27	23
Blodgett	Untreated	46.77	.101	2	1.72	74
	Understory removed	45.82	.101	4	1.67	74
	75% original basal area	34.34	.081	10	1.27	60
	50% original basal area	24.21	.056	10	0.93	44
	25% original basal area	12.73	.027	15	0.44	27
Tenderfoot	Untreated	42.69	.112	2	1.00	52
	Understory removed	38.64	.111	5	0.91	60

	75% original basal area	32.66	.093	5	0.78	52
	50% original basal area	21.06	.060	6	0.51	40
	25% original basal area	7.87	.028	10	0.21	24

2. Canopy bulk densities in untreated stands ranged from 0.09 to 0.26 kg/m^3. These stands were chosen because they were dense and judged by local managers to be prone to crown fire. FARSITE (Finney 1998) uses a default value of 0.2 kg/m^3 for canopy bulk density. Cruz and others (2003) report a mean derived canopy bulk density of 0.18 kg/m^3 for ponderosa pine and Douglas-fir stands, 0.28 for lodgepole pine, and 0.32 for mixed conifer. Agee (1996) suggests that reducing canopy bulk density to .10 kg/m^3 or less should effectively reduce the risk of crown fire. Our observations suggest that these values may be high. In fact, FARSITE has recently been modified as a result of this study to perform more realistically at the observed range of canopy bulk densities.

3. Correlations were published between readings taken from several optical sensors and canopy fuel caharacteristics (Keane and others 2005).

4. A photoguide was published (Scott and Reinhardt 2005).

5. Methods were further developed for predicting canopy fuel characteristics from stand data (Gray and Reinhardt 2003, Reinhardt and others in press).

Deliverables:

Proposed	**Accomplished**
• An operational procedure for indirect measurement of canopy characteristics.	The procedure has been developed. Protocols will be published in a Rocky Mountain Research Station Research Note.
• A methodology for destructive sampling of canopy fuel characteristics suitable for further research into canopy fuels and crown fire behavior.	Methodology has been developed, was used in this study, and is documented in detail in the study plan on file at the Missoula Fire Lab. In less detail, the methodology is documented in Reinhardt and others, in press.
• Verification of the accuracy of	These results have been published in Keane and others

existing and alternative methods of estimating important canopy fuel characteristics against data collected by destructive sampling in five stands in different forest types.	2005 and Reinhardt and others, in press.
• A detailed dataset of canopy characteristics (bulk density by size class, live/dead component, and vertical position within the stand) for a range of stand types and fuel treatments.	These results have been published in Scott and Reinhardt 2005.
• A photo guide with stereo-pair color photos of each stand after each level of destructive sampling. This guide will have 20 stereo pairs	Scott and Reinhardt 2005.
• A database that contains and documents the raw field data collected for this study. We anticipate that this data will be useful for a number of other studies.	On file at the Missoula Fire Lab. We hope to archive the entire data base as a web publication shortly.
• A computer simulation program that allows fire managers and silviculturists to simulate treatments and judge the effects on canopy fuels.	FuelCalc, under development at the Missoula Fire Lab and available by request. This program is being used to develop the canopy fuel layers for Landfire.

Publications:

Scott, J.H. and Reinhardt, E.D. Estimating canopy fuels in conifer forests. Fire Management Today 62(4): 45-50. 2002.

Gray, K.L., Reinhardt, E.D. 2003. Analysis of Algorithms for predicting canopy fuel. In: Proceedings of the Second International Wildland Fire Ecology and Fire Management Congress and Fifth Symposium on Fire and Forest Meteorology, November 16-20, 2003, Orlando, FL. American Meteorological Society.

Keane, R.E., Reinhardt, E.D., Scott, J., Gray, K., Reardon, J. 2005. Estimating forest canopy bulk density using six indirect methods. Canadian Journal of Forestry Research 35:724-739.

Scott, Joe H., Reinhardt, Elizabeth D. 2005. Stereo photo guide for estimating canopy fuel characteristics in conifer stands. Gen. Tech. Rep. RMRS-GTR-145. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 49 p.

Scott, Joe H., Reinhardt, Elizabeth D. in press. Effects of alternative treatments on canopy fuel characteristics in five conifer stands. PSW-Proceedings, National Silviculture Workshop.

Reinhardt, E.D., Scott, J.H., Gray, K.L. and Keane, R.E. Estimating canopy fuel characteristics in five conifer stands in the western United States using tree and stand measurements. Accepted pending revision at Canadian Journal of Forest Research.